Gamex CR 2.0

Program description and operating manual

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1. Introduction

Gamex CR 2.0 is an advanced exposure time calculator developed for Computed Radiography (CR) carried out with gamma-ray sources of Ir-192, Se-75 and Co-60. It provides basic technical support for RT personnel involved in planning and executing of radiographic examinations using CR technology.

Gamex CR 2.0 is the second, modified version of *Gamex CR* program which was the first exposure time calculator on the market intended for Computed Radiography. The greatest novelty in this version is a fundamental change in exposure time calculation methodology. It is no longer based on ISO/CEN speed of IP plates as this approach proved to have some conceptual shortcomings and create practical problems for the program users. The most important one was the necessity to determine the ISO/CEN speed of the used CR system strictly in line with EN 14784-1 or ASTM E2446-05 standard. The correct implementation of the relevant procedures is rather difficult for the average industrial RT laboratory and obtained data are heavily dependent on the CR system setup. On the other hand, ISO/CEN speed data published by the CR systems manufacturers are not always adequate for testing with gamma-ray sources and typically lead to underestimated exposure times.

Calculation of exposure times in *Gamex CR 2.0* is based on *first principles* approach what means that whole CR process is theoretically modeled starting from the gamma-ray emissions at the radioactive source and finishing at the gray level image retrieved by the CR reader from the exposed IP plate. Physical backgrounds and calculation principles are described in more details in sections 7 of this manual. From the user perspective the most important aspect of this approach is the fact that the basic parameter controlling the exposure time (in a similar way as the film density) is the normalized Signal to Noise Ratio (nSNR) of the digital radiograph. To calculate the exposure time for the typical CR examination the user needs to enter to the program the standard exposure parameters (source activity, material thickness, source to IP distance), imaging plate type, thickness of metal screens if used, and nSNR required for the radiographic image. Speed (sensitivity) of the IP is no longer required as it is effectively calculated by the program based on a given IP type and CR system parameters specified in the program options.

The CR system parameters are preset in the program options for typical values found in modern CR systems. The advanced users can replace this data with more accurate data taken from independent measurements or CR system specifications. In most cases, the predefined parameters are accurate enough to ensure reasonable accuracy of calculated exposure times.

The program logic and user interface is optimized for the most commonly used international standards on Computed Radiography (EN 14784-1, prEN ISO 17636-2, ASTM E2446-05). The user can select the governing standard in the program options and develop radiographic techniques in line with its requirement. The prepared techniques can be saved and printout in the form of condensed test cards listing all parameters necessary for their execution by qualified personnel.

Gamex CR 2.0 will operate on the following Windows platforms: Windows XP, Windows Vista, Windows 7 and Windows 8.

The program offers the following functionality:

- Calculation of exposure times for CR examinations executed with Ir-192, Se-75 or Co-60 gamma-ray sources based on the required SNR of digital image.
- Possibility to perform calculations for standard (ST), high resolution (HR) and ultra-high resolution (UR) imaging plates.
- Possibility to perform calculations for bare IP or IP with metal screens.
- Definition of the basic IP/CR system parameters in the program options.
- Compensation of exposure times for the IP fading effect.
- Correct calculation of exposure times for single-wall and double-wall exposure techniques
- Possibility to perform calculations for items made of steel, nickel, copper, aluminum and titanium.
- Integrated database with parameters of gamma-ray sources with automatic calculation of their current activities.
- Possibility to develop and printout complete radiographic techniques with all parameters necessary for their application by qualified RT personnel.
- Optional selection of preferred length, temperature and activity units.
- Optional selection of the governing CR standard.
- Program Help system with detailed description of all program functions.

2. Program interface

After successful installation and registration of the *Gamex CR* program you can start it by double clicking on the shortcut icon placed by the installer on the Windows desktop (fig.1).

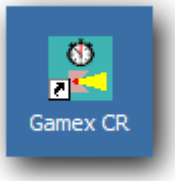

Fig. 1. Gamex CR shortcut icon on the Windows desktop.

The main program window is displayed where you can perform exposure time calculations and reach all its basic functions, options and help files.

There are two buttons placed on the top panel and three tabs placed on the main panel.

- The **Program Info** button displays the form with the program name, version and registration information. If the program has not been registered yet this button is named **Registration** and serves as a starting point for the program registration procedure.
- The **Help** button opens the program help system.
- The **Exposure time** tab opens the main program page where exposure time calculations are executed.
- The **Gamma-ray sources** tab opens the page with the table of gamma-ray sources stored in the program database. On this page you can enter, edit or delete your gamma-ray sources.
- The **Options** tab opens the page where you can make selection of preferable units and governing CR standard, set basic parameters of your IP/CR system and inspection related data necessary for calculation of fading correction.

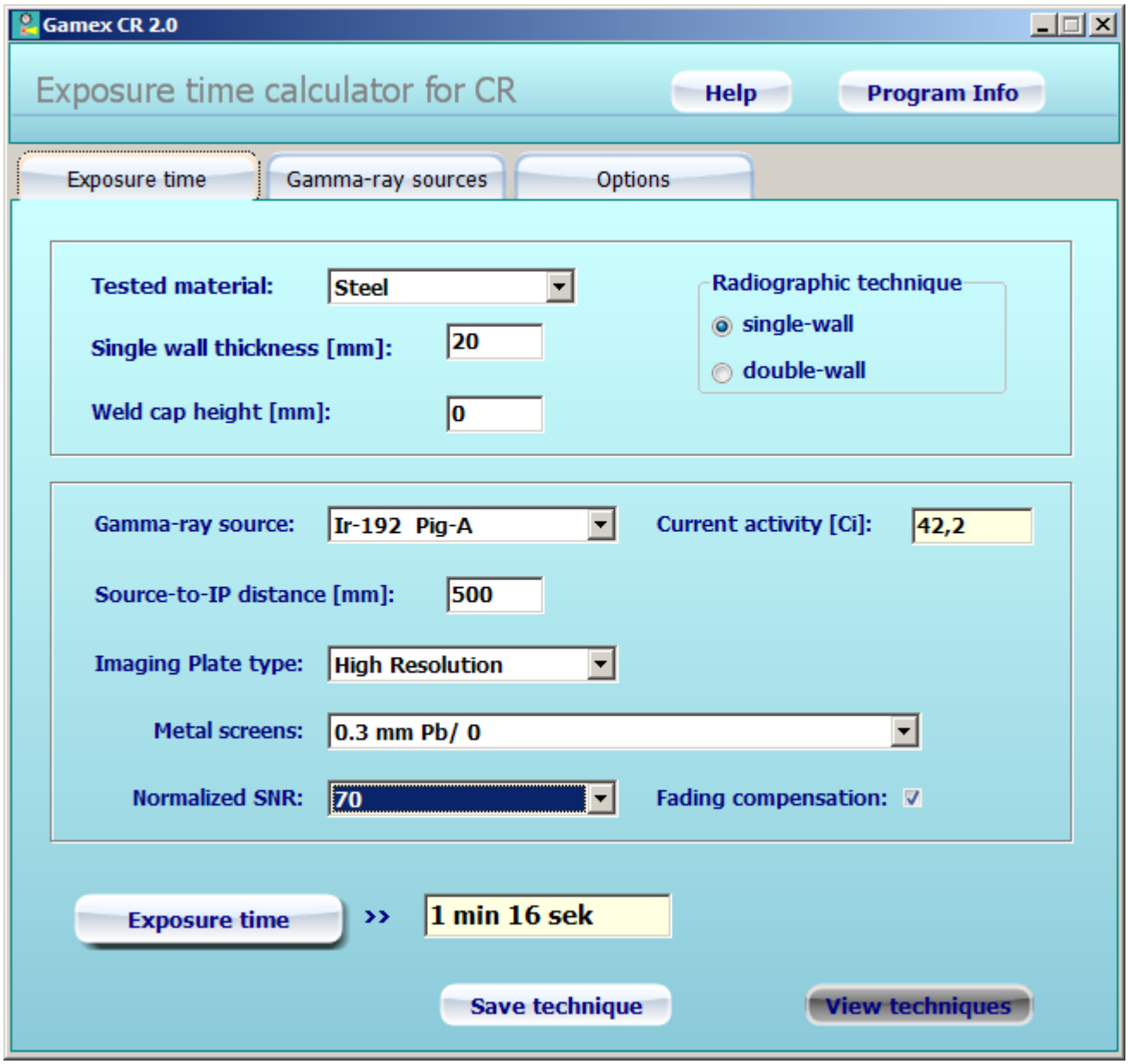

Fig. 2. The main window of the Gamex CR program.

3. Setting the program options

After successful installation and registration of *Gamex CR* program you need to set up its basic options and enter parameters of gamma-ray sources used in the laboratory. To set the program options click on the **Options** tab in the main window and open the following page:

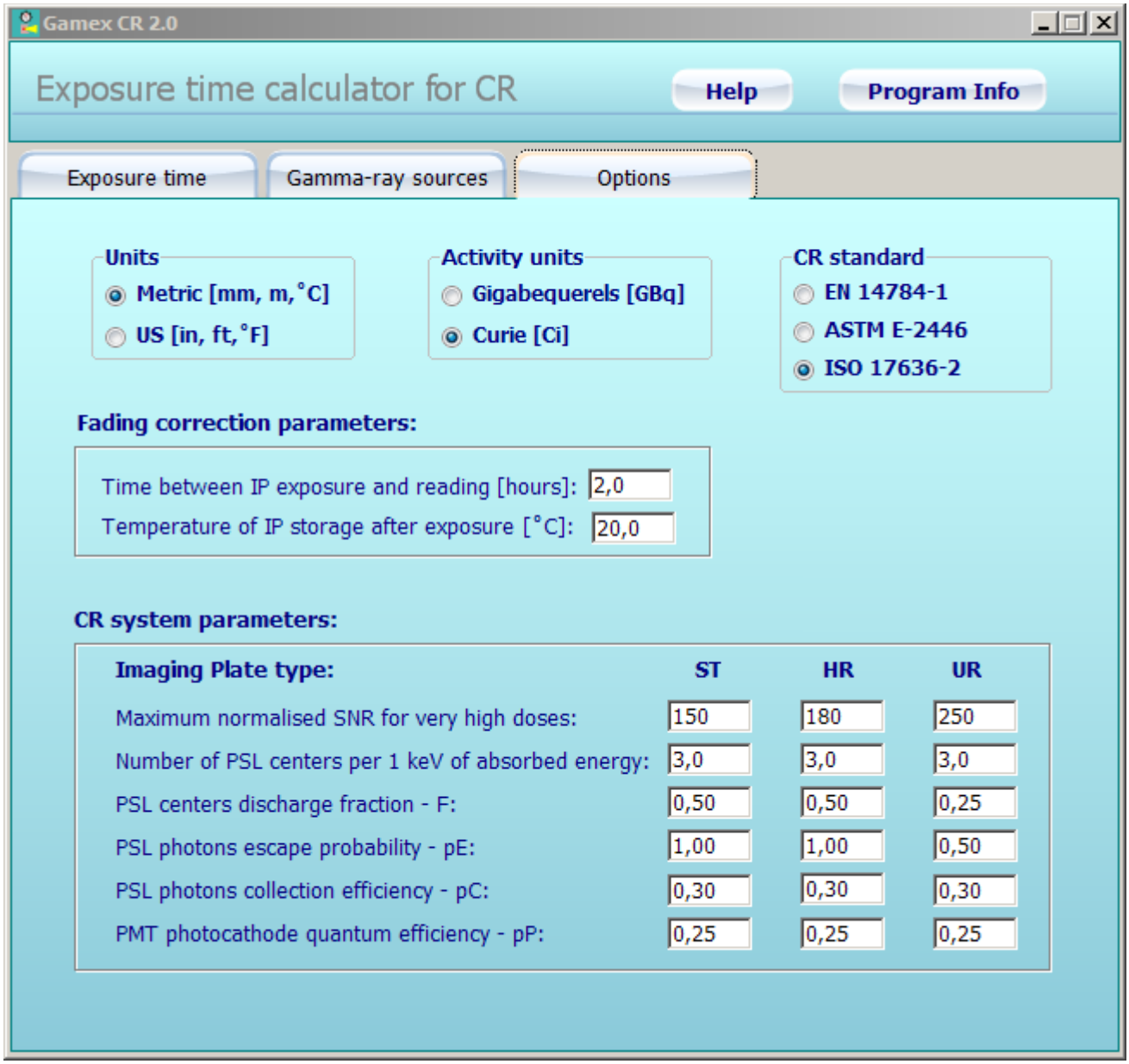
Gamex CR 2.0
Exposure time calculator for CR
Help
Program Info
Exposure time
Gamma-ray sources
Options
Units
Metric [mm, m, °C]
US [in, ft, °F]
Activity units
Gigabequerels [GBq]
Curie [Ci]
CR standard
EN 14784-1
ASTM E-2446
ISO 17636-2
Fading correction parameters:
Time between IP exposure and reading [hours]: 2,0
Temperature of IP storage after exposure [°C]: 20,0
CR system parameters:
Imaging Plate type: ST HR UR
Maximum normalised SNR for very high doses: 150 180 250
Number of PSL centers per 1 keV of absorbed energy: 3,0 3,0 3,0
PSL centers discharge fraction - F: 0,50 0,50 0,25
PSL photons escape probability - pE: 1,00 1,00 0,50
PSL photons collection efficiency - pC: 0,30 0,30 0,30
PMT photocathode quantum efficiency - pP: 0,25 0,25 0,25

Fig. 3. Definition of program options.

In the ***Options*** tab make the following settings:

- In the *Units* panel select the preferred system of physical units, *Metric* or *US*.
- In the *Activity units* panel select the preferred source activity units, *GBq* or *Ci*.
- In the *CR standard* panel select the Computed Radiography standard which typically governs your examinations.
- In the *Fading correction parameters* panel enter the typical time and temperature your exposed IP are kept before reading in CR scanner.

Parameters contained in the *CR system parameters* panel are preset for typical values applicable for most CR inspections performed with use of basic IP types (ST, HR, UR). They may be adjusted by advanced users with more accurate data taken from independent measurements or CR systems specifications. Basic description of these parameters is given in the last section of this manual. In most cases, the predefined parameters ensure reasonable accuracy of calculated exposure times but for most demanding or nonstandard applications the users should establish and enter to the program actual parameters of their CR systems.

After making your choices just go to another program page and your preferences will be saved in the program database. All subsequent program operations will be executed in accordance with this setup.

4. Entering gamma-ray sources

Before starting normal program operation of you need to enter parameters of your gamma-ray sources to the program database. To specify parameters of your sources click on the ***Gamma-ray sources*** tab in the main window and open the page shown in fig. 4. There is a table with parameters of all gamma-ray sources stored in the program database.

When you open this page for the first time you may find there some example entries of gamma-ray sources which can serve you as the templates for introducing parameters of your actual sources. You may open the selected source by clicking on the ***Edit source*** button or double clicking on the relevant table row.

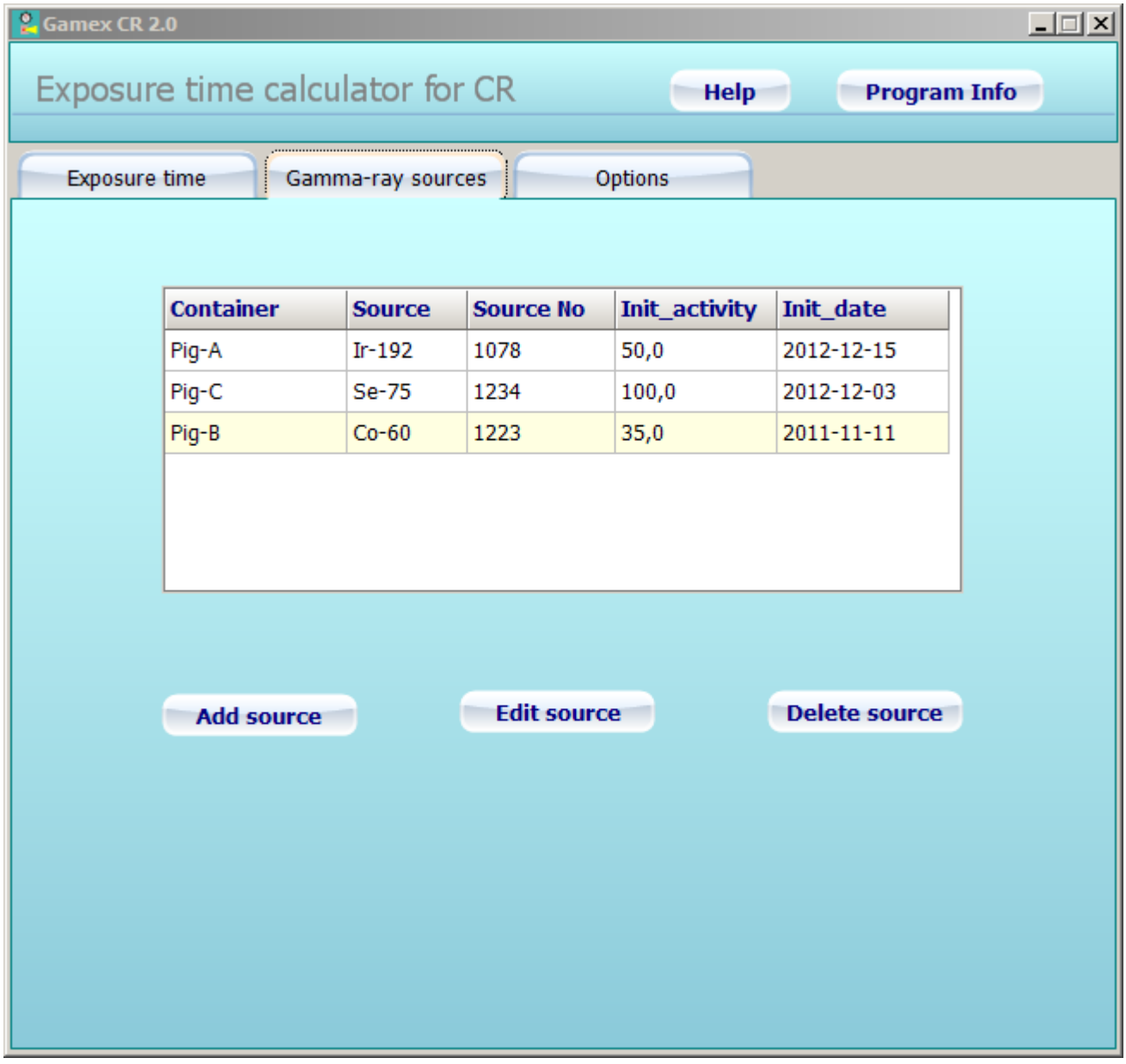

Fig. 4. Table of gamma-ray sources stored in the program database.

Alternatively, you may enter the new sources by clicking on the ***Add source*** button and filling in the form shown in fig. 5.

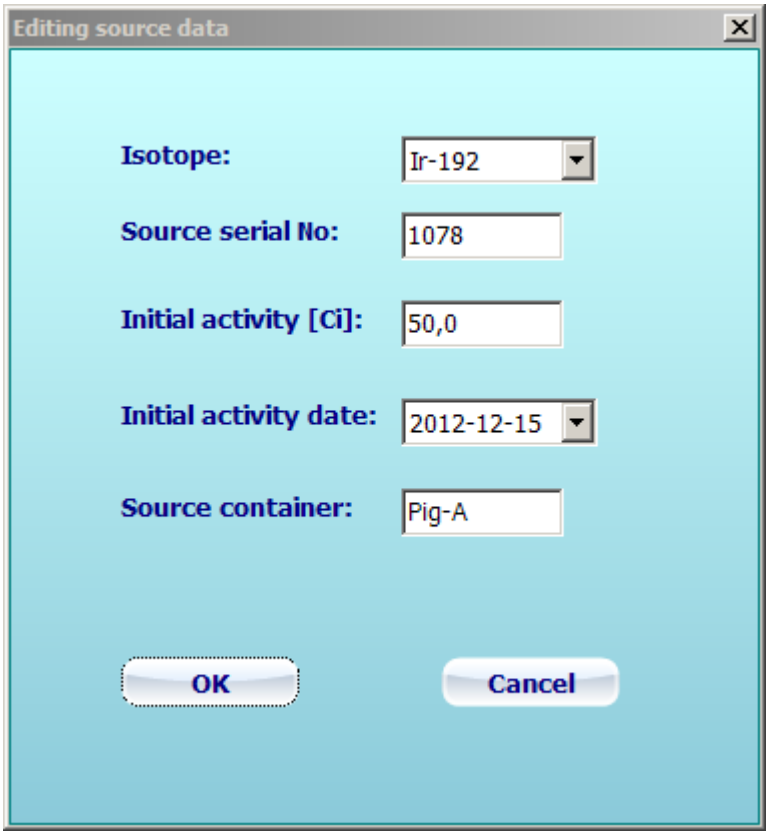

Fig. 5. Entering parameters of the new gamma-ray source.

In the form enter the following data:

- In the *Isotope* combo box select the type of the new gamma-ray source. You may choose one of the three options: Ir-192, Se-75 or Co-60.
- In the *Source serial No* field enter the serial number of the gamma-ray source. The number should be given in the source certificate.
- In the *Initial activity* field enter the initial activity of the source as indicated in its certificate. The activity value may be expressed in [GBq] or [Ci] depending on the choice made in the program options.
- In the I*nitial activity date* data picker pick up the date of the initial activity measurement. This information should be given in the source certificate together with the activity value.
- In the *Source container* field enter the short identification (symbol/number) of the container your gamma-ray source was loaded in. It should unambiguously identify the source for RT operators and program users.

After entering all above data click on the **OK** button and find your new source in the table gamma ray sources displayed on the ***Gamma-ray sources*** tab.

5. Calculation of exposure time

To calculate exposure times for the planned CR techniques click on the ***Exposure time*** tab and open the program page shown in the fig. 6.

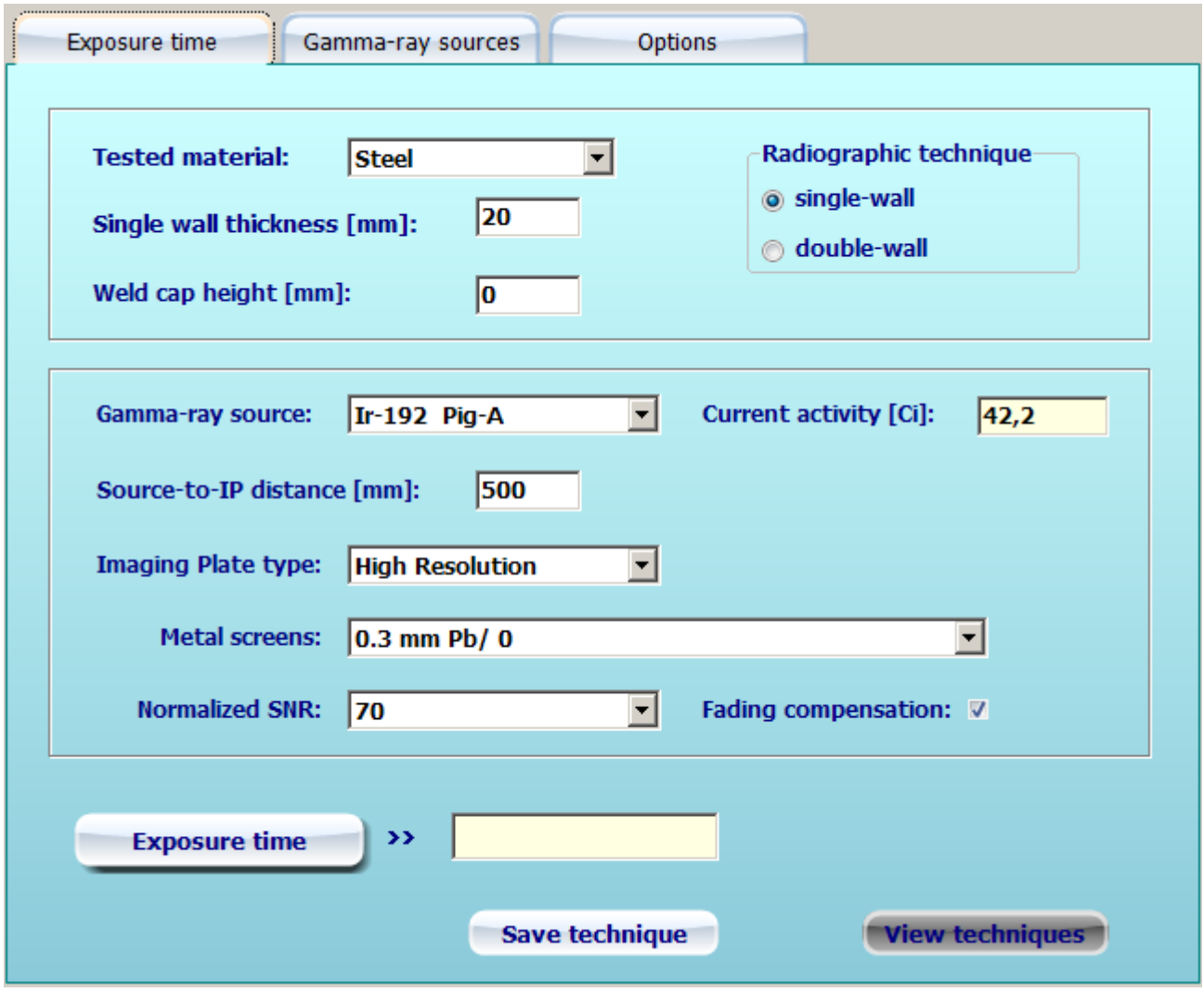

Fig. 6. Definition of CR technique parameters for calculation of exposure time.

In the opened page define the following exposure parameters of radiographic technique:

- In the combo box *Tested material* select the material to be tested. You can select one of the following materials: steel, nickel, cooper, titanium or aluminum.
- In the edit box *Single wall thickness* enter the wall thickness of the tested object. You should always put here the single wall thickness, even for double wall exposure techniques.
- In the edit box *Weld cap height* enter the estimated height of the weld caps when testing welds. In other cases enter zero.

- In the radio group *Radiographic technique* select the geometry of radiographic exposure. You should choose *single-wall* or *double-wall* exposure technique. The selection is very important for correctness of exposure time calculations as it determines the total penetrated thickness and the way the program accounts the scattered radiation.
- In the combo box *Gamma-ray source* select the source which will be used for the exposure. The sources available are those which have been entered to the program database. After the selection of the gamma-ray source the program automatically calculates its current activity and displays it in the *Current activity* box. You can overwrite this value manually if necessary.
- In the edit box *Source-to-IP distance* enter the distance between the gamma-ray source and IP plate which will be used in the planned examination.
- In the combo box *Imaging Plate typ*e select the type of imaging plates which will be used in the examination. You can select S*tandard Resolution (ST),* H*igh Resolution (HR)* or *Ultra-High Resolution (UR)* type of plate. The type of IP is defined by the thickness of the storage phosphor layer: *ST* – c.a. 300 μm, *HR* – c.a. 150 μm, *UR* – c.a. 110 μm.
- In the combo box *Metal screens* select the combination of front/back metal screens which will be used with the IP plate during exposure. You may select one of typical screens combinations recommended by the CR standards or exposure without any metal screens.
- In the combo box *Normalized SNR* specify the nSNR value required for your digital radiographs. The predefined nSNR values available for selection depend on the CR standard specified in the program options. For example, for EN 14784-1 standard you can select one the following values: 130, 113, 78, 65, 52 or 43.
- By marking the *Fading compensation* check-box you may switch on correction for the fading effect of the exposed IP. The correction is calculated on the bases of fading correction parameters introduced in the *Options* tab.

After entering all the above data, click on the **Exposure time** button and calculate the exposure time necessary for your radiographic technique. The calculated exposure time will be displayed in the adjacent box in hr, min, sec format.

You can save all parameters of the specified radiographic technique by clicking on the **Save technique** button. Then you can repeat calculations for other sets of exposure parameters and save the results in the same way. The saved techniques can be reviewed and printed out in a separate window which opens by clicking on the **View techniques** button. Further details are described in the next section.

6. Printing the radiographic techniques

Radiographic techniques prepared and saved in the ***Exposure time*** tab can be reviewed in a separate program window opened by clicking on the ***View techniques*** button. An example content of the window named ***Radiographic techniques*** is shown in fig. 7. The window contains table of radiographic techniques saved in the current program session. Each row of the table specifies parameters of one radiographic technique.

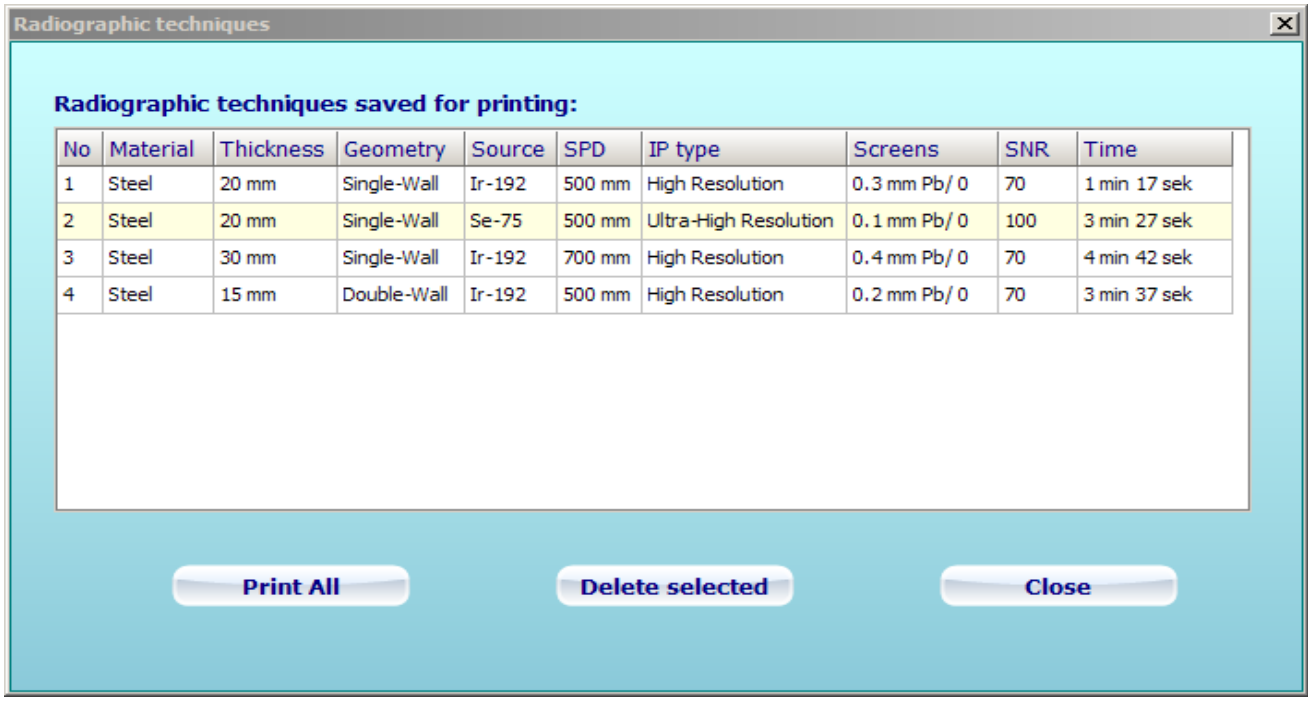
Radiographic techniques
Radiographic techniques saved for printing:
No Material Thickness Geometry Source SPD IP type Screens SNR Time
1 Steel 20 mm Single-Wall Ir-192 500 mm High Resolution 0.3 mm Pb/ 0 70 1 min 17 sek
2 Steel 20 mm Single-Wall Se-75 500 mm Ultra-High Resolution 0.1 mm Pb/ 0 100 3 min 27 sek
3 Steel 30 mm Single-Wall Ir-192 700 mm High Resolution 0.4 mm Pb/ 0 70 4 min 42 sek
4 Steel 15 mm Double-Wall Ir-192 500 mm High Resolution 0.2 mm Pb/ 0 70 3 min 37 sek
Print All
Delete selected
Close

Fig. 7. Table of radiographic techniques saved in the current program session (example).

In the window you may select techniques to be printed. To remove the unwanted technique from the printout table place the cursor on its row and click on the ***Delete selected*** button. The technique will be deleted from the table and from the program memory.

After removing all unwanted entries you can print out the remaining techniques by clicking on the ***Print All*** button. The printout specify all parameters of the prepared radiographic techniques necessary for their proper execution by qualified RT personnel. The example printout of test card with parameters of 3 radiographic techniques is shown in fig. 8.

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Technique #1

Tested material:	Steel
Wall thickness:	20 mm
Weld cap height:	0 mm
Exposure geometry:	Single-Wall
Gamma-ray source:	Ir-192 Pig-A
Source activity, A:	41,8 Ci
Source-to-detector distance:	500 mm
Imaging Plate type:	High Resolution
Front screen/ Back screen:	0.3 mm Pb/ 0
Normalized SNR (IPx):	70
Fading correction:	2,0 h /20°C
Exposure time:	**1 min 17 sek**

Technique #2

Tested material:	Steel
Wall thickness:	20 mm
Weld cap height:	0 mm
Exposure geometry:	Single-Wall
Gamma-ray source:	Se-75 Pig-C
Source activity, A:	83,6 Ci
Source-to-detector distance:	500 mm
Imaging Plate type:	Ultra-High Resolution
Front screen/ Back screen:	0.1 mm Pb/ 0
Normalized SNR (IPx):	100
Fading correction:	2,0 h /20°C
Exposure time:	**3 min 27 sek**

Technique #3

Tested material:	Steel
Wall thickness:	15 mm
Weld cap height:	2 mm
Exposure geometry:	Double-Wall
Gamma-ray source:	Ir-192 Pig-A
Source activity, A:	41,8 Ci
Source-to-detector distance:	500 mm
Imaging Plate type:	High Resolution
Front screen/ Back screen:	0.2 mm Pb/ 0
Normalized SNR (IPx):	70
Fading correction:	2,0 h /20°C
Exposure time:	**3 min 37 sek**

Fig. 8. Example test card with parameters of 3 radiographic techniques.

7. Advanced considerations

7.1. Physical backgrounds

The program is based on advanced mathematical model describing physical processes taking place in Computed Radiography. They start from emission of gamma rays from isotope source and end up with creation of digital radiographic image in the computer memory. From the point of view of mathematical modeling the whole CR process can be divided into three main stages: exposure of imaging plate with gamma rays penetrated through the tested object, storing the latent image in the phosphor layer of IP plate and reading the latent image in the CR reader. The stages are described below in more details.

During radiographic exposure the gamma rays emitted from the source propagate through the tested material undergoing multiple scattering and absorption. The radiation transmitted through the tested object falls on the imaging plate and is partially absorbed in their storage phosphor made of small crystals of $BaFBr_{0.85}I_{0.15}:Eu^{2+}$ mixed with the organic binder. Part of the absorbed energy is deposited in the form of, so called, photostimulable centers (*PSL* centers) which are specific crystal defect complexes with trapped electrons and holes located nearby the Eu^{2+} dopant ions. The latent image is built up through the accumulation of PSL centers in the phosphor layer. The number of PSL centers created in a given phosphor volume is proportional to the radiation dose absorbed in that volume. According to various studies, from 3 to 8 PSL centers is created per 1 keV of absorbed gamma-ray energy.

The created PSL centers are metastable what means that they slowly disappear due to spontaneous discharge of the electron traps. Loss of PSL centers in the exposed phosphor means that the latent image fades with time. The fading rate depends on the temperature and type of imaging plate. The fading effect must be taken into consideration as it reduces the intensity of radiographic image retrieved from IP by CR scanner. There are mathematical formula available in the literature which precisely describe this process.

Readout of latent image is performed with a raster laser scanner which scans the exposed IP point by point. The trapped electrons are liberated by the laser light photons and recombine with the trapped holes. The recombination is connected with excitation of the nearby Eu^{2+} ions which promptly release the acquired energy by emission of photoluminescent blue photon. The emitted PSL photons are partially collected by the light guide and directed to the photomultiplier tube (PMT) of the CR reader. Only a fraction of PSL photons reaching the PMT photocathode cause emission of photoelectrons which form the initial current of the photomultiplier tube. The initial current is amplified at the photomultiplier dynodes and form the PMT output signal. The output signal is low pass filtered and digitized with an A-C converter. The digital signal intensity data are combined with the corresponding position coordinates of the scanning laser spot and saved in the computer memory. The recorded information is used by the computer software to display the gray level image representing the distribution of PSL intensity on the scanned IP surface. In most CR systems the gray levels of the produced image are not directly proportional (linear) to the PSL intensity but rather to the Log or Square root of this value. It should be taken into consideration when calculating SNR of registered images as this fundamental image parameter must be calculated from the pixel values linearized to the actual PSL signal intensity.

7.2. Calculation principles

The basic parameter of image quality in Computed Radiography is normalized Signal to Noise Ratio nSNR. The nSNR of digital radiograph is directly controlled by the exposure of imaging plate. So, the principal problem in Computed Radiography is to determine exposure time so that the resulting digital radiograph had required normalized SNR.

The *Gamex CR 2.0* program solves this problem using the mathematical model of CR process based on the *first principles*. The main objective of the program is to determine functional dependence between normalized SNR of digital radiograph and exposure time of IP for a given set of testing conditions. This relation is highly complicated and depends on many factors such as: the source type and activity, source-to-IP distance, thickness of tested material, exposure geometry, type of IP, type and thickness of front and back screens, time and temperature of IP storage after exposure and CR reader parameters set during IP scanning.

To model CR process the program performs the several calculation steps based on parameters defined in the program options and entered by the user for particular exposure:

- Based on the source type, activity and distance from the tested object calculation of the number of gamma ray photons incident on the unit area of tested object per unit time is performed. For this purpose program uses the law of radioactive decay, inverse square law and information on gamma emission energies and fractional yields for the selected radioactive source.
- Based on tested material thickness and exposure geometry the intensity and energy spectrum of radiation transmitted through the tested object is calculated. For this purpose the advanced radiation transport theory is used.
- Based on known parameters of imaging plate type and user selected combination of front and back screens the amount of radiation energy absorbed in the phosphor layer of IP is calculated. The calculation is based on the absorption coefficients of the storage phosphor layer and adjacent metal screens.
- Based on the known number of PSL centers created in the storage phosphor per 1 keV of absorbed energy the total number of PSL centers created on the standard pixel area (88,6 x 88,6 μm) of imaging plate is calculated.
- Based on user entered data on the temperature and time of exposed plate storage before reading, the fading factor is calculated. It determines the fraction of PSL centers that can survive until the latent image is retrieved in the CR reader.
- Based on the final number of PSL centers, their discharge fraction (F) and escape probability (pE) the number of PSL photons emitted from the standard pixel area of IP is calculated. Then, based on the reader light-guide photon collection efficiency (pC) the number of PSL photons reaching the photomultiplier tube (PMT) photocathode is calculated. In the last step the number of photo-electrons emitted from PMT photocathode is calculated based on its quantum efficiency (pP). This number can effectively represent the intensity of PSL signal during scanning of exposed imaging plate. Due to the practically noiseless gain in PMT the linearized pixel value of the digital image is proportional to this number.

- In the above calculation steps, except the average values of specific quantities, also their statistical variances are calculated. This way both the signal and its noise is known at the consecutive stages of CR process.

- Except of the inherent photonic noise transmitted through the stages of the CR process an additional noise caused by the structural inhomogeneity of imaging plate arises at the IP readout stage. The nSNR of structural noise is independent of the IP exposure and for very high doses is the dominant part of the measured nSNR. Due to this feature its value can be deduced from nSNR of test radiographs taken at very high doses specified in the program parameter *Maximum normalized SNR for very high doses*.

- In the final step the total normalized SNR of digital image is calculated in dependence of the exposure time of IP plate. Reversing this relation we can calculate exposure time necessary to obtain digital radiograph with required normalized SNR.

7.3. CR system parameters

CR system parameters displayed in the ***Program options*** tab are mostly related to the equipment and consumables used in CR examinations. They can be set once for the given IP/CR system and generally kept constant during normal program use.

The CR parameters are defined separately for different ***Imaging Plate types***. Imaging plate types define the basic properties of imaging plates and are loosely associated with commercially available IP types. The basic characteristics of IP types defined in the program are specified below:

- The *Standard Plates (ST)* are defined as IP for general use with standard resolution and thickness of phosphor layer of about 300 μm. The backing layer of these plates is absorptive for stimulating laser light and reflecting for the blue PSL light.

- The *High Resolution Plates (HR)* are higher resolution plates with thickness of phosphor layer of about 150 μm and backing layer which is absorptive for stimulating laser light and blue PSL light.

- The *Ultra-High Resolution Plates (UR)* are the highest resolution plates with thickness of phosphor layer of about 110 μm and backing layer which is absorptive for stimulating laser light and blue PSL light. Additionally, its active phosphor layer contains blue pigment which considerably absorbs the stimulating laser light.

The ***CR system parameters*** are defined as follows:

- The ***Maximum normalized SNR for very high doses*** specify the SNR obtained for a given type of plate when it is exposed to radiation dose, at least 10 times greater than normally required for IP 1 class. It is the most important CR system parameter and should be established using scanning parameters of CR reader typically used for production radiographs.

- The ***Number of PSL centers per 1 keV of absorbed energy*** is established based on the technical literature and is conservatively preset to 3. If the user has better estimate of this parameter for a given storage phosphor he can replace this value accordingly.

- The ***PSL centers discharge fraction - F*** depends on the scanning laser parameters (laser power, scanning speed and scanning resolution). The predefined value of 0.5 is reasonable compromise between high sensitivity and high resolution. The user can determine the discharge fraction for a given set of scanning parameters by rereading the uniformly irradiated IP plate second time and measuring the average PSL intensities: I_1 and I_2 in the first and second scanning. The resulting discharge factor F is approximately given by the formula:

$$F = 1 - \frac{I_2}{I_1}$$

- The ***PSL photons escape probability – pE*** is set to 1 for plates with reflective backing for PSL photons and to 0.5 for plates with absorptive backing for PSL photons. This value could be smaller for UR plates with blue dye.

- The ***PSL photons collection efficiency – pC*** is determined by the construction of CR reader waveguide which collects PSL photons emitted from the IP during scanning. It is conservatively set to 0.3 but can possibly be higher for modern CR readers. The user can get information on this parameter from the CR system manufacturer.

- The ***PMT photocathode quantum efficiency – pP*** is determined by the construction of photomultiplier tube. The preset value of 0.25 is typical for modern PMT designs and is not likely to became higher in the near future.

It should be noted that CR system parameters described above, except the ***Maximum normalized SNR for very high doses***, do not have too much impact on the calculated exposure times. So their predefined values should ensure reasonable accuracy of exposure time calculations in most practical cases.